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Integrating Mathematics, Science, and Technology
Effects on Students

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Abstract

Few studies have examined the student learning effects of integrating science with mathematics and technology. We compared a school that integrated mathematics, science, and technology in grade 9 to a school in the same district that taught the three courses separately. The distinguishing feature of the integrating school was the reorganization of instruction in the three subjects to prepare students for seven group projects (involving a total of 25 hours) that required the application of knowledge and skill that were shared by the three subjects as well as learning outcomes that were unique to each. The study detected benefits for students in the integrated setting in terms of their ability to apply shared learning outcomes, student motivation, ability to work together, and attitudes to appraisal of group work. Female students in the integrated school had a better understanding of selected science learning outcomes. Attitudes toward mid-term exams were higher in the control school.

Integrating mathematics, science, and technology: Effects on Students

Curriculum integration is recommended by national organizations such as School science and mathematics (e.g., Underhill, 1995), the National Council of Teachers of mathematics (NCTM, 1991), and the American Association for the Advancement of science (Yager & Lutz, 1994). Yet few studies of the effects of integrated programs have been reported. This article reports a study that examined student outcomes in one integrated setting.

The integrated program studied was refined over a four-year period. Teachers in three subjects (mathematics, science, and technology) covered the grade 9 courses mandated by the province in their own classrooms. The MST program differed from teaching in segregated settings: (a) At various times during the year (seven occasions in the first semester of 1995-96) students worked in three person teams to plan, construct, and evaluate a single group product (e.g., a model of a bridge). These projects took about 25 hours, representing 10% of the instructional time allocated to the three subjects. To complete the projects students needed to apply knowledge and skills unique to each subject and apply learning outcomes shared by them all. (b) The sequence of topics within disciplines was re-arranged so that students had knowledge at the time they needed it for each project. Teachers met frequently to ensure continuity among the subjects. (c) Teachers emphasized skills that were shared by all three subjects, such as the district's five-step inquiry model, a generic approach to problem solving. (d) Less important content was given little attention or was deleted entirely in order to make room for the culminating project activities.

Theoretical Framework

Defining Curriculum Integration

Neither curriculum theorists nor practitioners have reached agreement on how curriculum integration should be defined (Davison, Miller, & Metheny, 1995), even though science and mathematics integration has been vigorously pursued since the 1930s (McBride & Silverman, 1991). In this study integration meant organizing course content around a series of projects, i.e., culminating events that require the application and assembly of an array of outcomes taught in different subjects (Berlin & White, 1994; LaPorte & Sanders, 1993; Sanders, 1994).

Potential Impact of Integration on Students

A variety of rationales have been offered for integrating mathematics, science, and technology. Not all of these are directly related to student achievement. For example, integration might increase cross-departmental conversations of teachers, thereby contributing to a collaborative school culture rather than a culture defined by norms of privacy and allegiances to home departments (Hargreaves, 1994). The emergence of a collaborative school culture might have an indirect effect on student achievement if high quality instructional ideas that had previously been isolated in one department began to flow to others. In addition, there is extensive evidence that a culture of teacher collaboration contributes to increased student achievement by influencing teachers' beliefs in their effectiveness (Ross, in press). Those who advocate curriculum integration because they believe it has direct effects on students cite several arguments. Three arguments--transfer, focus, and motivation—are considered below in the context of a project-based approach.

The transfer argument gives primacy to the ability of students to apply their knowledge when it is needed. Proficiency in application diminishes with distance from the context in which knowledge is first acquired. Instructional programs that require students to apply knowledge learned in one subject to problem solving in another might reduce the compartmentalization of knowledge that inhibits transfer. This would especially be the case in a project-centered approach in which students engage in authentic activities that approximate real world problem solving, tasks in which distinctions among subjects are blurred.

The focus argument is based on the belief that students are more likely to learn when their attention is focused on a few objectives rather than diffused among many. The argument has three facets. Most prominent is the claim that integration focuses student attention on the generic essentials shared by many disciplines. For example, Berlin and White (1994) identified a number of “big ideas” common to mathematics and science, such as balance, scale and models, and shared habits of mind such as skepticism, data-based decision making and willingness to consider alternate explanations. Integrated instruction might highlight these similarities. The second facet of the focus argument concerns complementarities. For example, mathematics and technology can contribute to science learning by giving students tools to build models of physical phenomena which can be refined by conducting actual and virtual experiments (Doerr, 1996; Roth, 1992; Roth & Bowen, 1994). The benefits can be reciprocal. For example, Roth (1993) found that an open inquiry physics program promoted attainment of the National Council of Teachers of Mathematics Standards. Less attention has been given to the third facet of the focus argument concerning the quintessentials, the unique differences that define the gist of each subject. These

include how a discipline organizes knowledge, the key concepts and the relationships among them, the evidence it is willing to accept in argument and the warrants for determining truth. Integration might reduce the likelihood that students would confuse problems that appear to be identical but have different solutions because they are embedded in different disciplinary frameworks. Tirosh & Stavy (1992) demonstrated that grade 7-12 students tend to give a common answer to two apparently similar problems drawn from mathematics/science: can a line/copper wire be divided in half indefinitely? The answer is yes for a line, which has no physical properties, and no for a wire that cannot be divided beyond the atomic level and still be copper. Curriculum integration might increase student learning by focusing student attention on important learning objectives such as those (i) that are shared by several subjects, (ii) where objectives in one subject that complement objectives in another, and (iii) objectives that distinguish disciplines.

The motivational argument is based on the belief that students like some subjects more than others. Curriculum integration encourages students to access less favored subjects through more favored ones. For example, by contextualizing mathematics activities in real world situations requiring scientific knowledge, integration might reduce the alienation some students feel in dealing with abstract problems (McBride & Silverman, 1991). Curriculum integration might have other affective benefits. Negative feelings about assessment that develop as students get older (Paris, Lawton, Turner, & Roth, 1991) might be assuaged in project-based integration which replaces end of unit tests with performance assessments. A project approach to curriculum integration might also increase students' ability to work together by providing additional practice in group activities that are perceived to be engaging and relevant.

These arguments suggest that curriculum integration could increase student achievement. But there is a counter-argument for each. For example, increasing cross-disciplinary conversations and focusing on shared objectives could lead teachers to lose track of the structure of the disciplines, their internal organization of ideas and principles. By emphasizing horizontal connections (integrating subjects) it might be more difficult for students to make vertical connections (e.g., integrating grade 9 learning with senior division learning in the subject). Integration could lead to fragmentation.

Previous Research

Only five empirical studies of the effects of integrating science with mathematics and technology have been reported. The studies are difficult to aggregate because they varied in terms of grade level (grade 2 to grade 12), instrumentation, duration, and research designs. The results were mixed.

Integrating mathematics and science had a positive impact on mathematics achievement in two studies (Austin, Hirstein, & Whalen, 1997; Mundform, Davis, Dickerson, & Briggs, 1996) but not in a third (Scarborough, 1993). The internal validity of Austin et al.'s study was threatened by the use of a post-only design in which the equivalence of the treatment and control groups was not established. Mundform et al.'s design was stronger (they tracked treatment and control students, grades 2-6, over several years) but in their study the effects of integration developed only after the first year of treatment. The need to accumulate effects over several years might explain why short duration treatments (e.g., Scarborough, 1993) found that integration had no achievement impact. There is also evidence that integration contributes to science achievement

(Friend, 1985; Mundform et al., 1996), although in one of the studies (Friend) the effects were limited to above average students.

Studies of integration's impact on affective outcomes produced consistent results. Integration contributed to improvements in mathematics confidence (Austin et al., 1997), enjoyment of science learning (Friend, 1985), preference for science activities (Scarborough, 1993) and classroom climate (Roth, 1992). Although the results were consistent, confidence in the findings is diminished by methodological problems. Neither Austin et al. nor Roth had a control group.

The results from these five studies were mixed, especially with regard to achievement. In addition, the evaluation designs used to measure the impact of integration suffered from threats to internal and external validity.

Research Questions

Given the lack of data on the effects of curriculum integration, a study was conducted to compare learning in two schools: Bayview High School, in which grade 9 mathematics, science, and technology courses were integrated into a single MST program, and Woodville, a similar school in the same district, in which the three subjects were taught separately. It was anticipated that students in the Bayview program would learn more than Woodville students in terms of (i) their ability to apply knowledge and skill unique to each discipline and shared by all three disciplines, (ii) motivation to learn, and (iii) ability to work together. It was further anticipated that (iv) their attitudes toward evaluation would become more positive.

Method

Sample

The data were collected in Bayview High School, a school with 53 teachers and 963 students (mostly white, lower middle class) located in a relatively stable community in Ontario, Canada. Data were provided by six teachers (two from each of mathematics, science, and technology) and 86 grade 9 students enrolled in MST in the first semester of 1995-96 who obtained parental permission to participate in the study. Comparative data were provided by three teachers (one in each subject) and 54 grade 9 students enrolled in the three subjects in the same semester in Woodville, a similar school in the same district with 64 teachers and 1069 students. Both schools operated within a provincial curriculum that provided strong support for curriculum integration without specifying the form integration should take or how it might be attained. The province specified instructional goals and was moving in some subjects (mathematics and English) toward stating standards of student performance. The means to reach these goals was determined by teachers, collaboratively in the case of Bayview and independently in the case of Woodville.

Instruments

At the beginning and end of the study students completed a motivation survey (Meece, Blumenfeld, & Hoyle, 1988) measuring their reasons for participating in a learning task. The survey consisted of 13 items with a four point scale (not at all true of me to very true of me). Three scores were generated: mastery orientation indicating a desire to participate in classroom activities in order to learn something, ego orientation (motivated by a desire to look good), and affiliative goals orientation (motivated by a desire to interact with friends). Previous research has

found that students with high mastery orientation scores consistently learn more (Urdan & Maehr, 1995).

The results of the motivation survey were used to place students in three person groups consisting of one student with a high mastery orientation, one with a high ego orientation score, and one with a high affiliative orientation. Students worked in groups on a pre-test project in which they had to construct a free standing tower using only 50 pieces of spaghetti, 30 miniature marshmallows, and a 22 cm X 28 cm paper towel. Students had approximately 100 minutes to complete the task. Each group was independently observed twice by each of four observers for 5-15 seconds, producing eight observations for each student. For each observation, student behavior was coded in one of six categories: on task alone (e.g., independently handling the materials or sketching a plan), handling materials cooperatively with another student, handling materials in conflict with another student, talking with another student about the project, watching other students build the project or listening to on-task conversations, and off-task behavior. Observation scores were aggregated across coders and across students within each group to produce six interaction scores for each group, representing the number of times each behavior was observed (potential range 0-8).

At the end of the study students returned to the same groups of three to construct a free standing machine to project a marble the farthest distance possible, using only 60 popsicle sticks, two sheets of 22 cm X 28 cm paper, 250 cm of masking tape, and one 20 cm X 20 cm piece of cardboard. Students were given approximately 100 minutes in which they made individual thumbnail sketches, selected one of their sketches and developed it into a single working drawing

for their group, and built a marble machine from the working drawing. During the planning and construction process teachers provided assistance as requested by groups (providing clues rather than explicit directions) and monitored student behavior. Students were observed as on the pre-test, except that each observer focused on each student once during the planning phase and once during the construction of the machine. Six interaction scores were generated for each group. The sketches and diagrams produced by each group were rated on eight characteristics derived from the provincial technology curriculum by a single coder using a 0-2 scale (0=none, 1=partly, 2=complete) for each indicator. The items, shown in Table 1, were summed to produce a 0-16 score.

Table 1 About Here

After completing their post-test projects, a random sample of students (21 in Woodville but only 18 in Bayview because 3 were lost for reasons unrelated to the research) were interviewed about their use of selected MST learning outcomes in planning and building their machines. Students were first asked “Can you think of a topic covered in technology class that helped you design, build, or evaluate your marble machine?” After students had responded to the open probe, they were asked about specific physical or intellectual tools that had been identified in advance of data collection by the nine teachers involved in the study.² For technology these were thumbnail sketches and aesthetics of the prototype (i.e., the extent to which students considered building a machine that looked capable of performing the function for which it was designed; in the case of the Marble Machine that meant a solid-looking piece of equipment with neat joints and even cuts). The same probes were repeated for science (the learning outcomes were forces such

as compression and tension, and braces such as cross braces, gussets or trusses), mathematics (the outcomes were the Pythagorean Theorem and geometry such as triangles, angles or parallel lines), and for outcomes that cut across all three subjects (the district's five step inquiry process, measurement, accuracy, and diagrams). Student responses were audio recorded. Prior to the data collection the six interviewers had participated in a pilot study using the same guide (Authors, 1996) and transcripts of the pilot interviews were used to refine probes and anticipate student responses.

The tapes were coded by the interviewer on three dimensions, as shown in Table 2: whether the learning outcome was identified (0-2), understood (0-2), and used (0-2), producing a score of 0-6 for each outcome. A random sample of 10 cases was recoded by a reliability coder producing Kappas (Cohen, 1960) of .74 for identification (agreement on 110 of 133 decisions), .63 for concept understanding (agreement on 83 of 110 decisions) and .75 on concept use (91 of 109 agreements). The reliability coder then recoded all interviews and discrepancies were adjudicated by the principal investigator. Since the number of learning outcomes varied by subject and students had the option of identifying additional outcomes, an average knowledge application score was constructed for each student for each of the three subjects and for the shared MST outcomes (i.e., four variables).

Table 2 About Here

All students completed an attitudes to evaluation survey following the interviews. The survey consisted of 10 items in two evaluation situations: a mid-term exam in science and appraisal of group work (the Marble Machine post-test was offered as an example). Students

responded on a five point agree-disagree scale to statements (half worded positively, the remainder negatively) about their perceptions of evaluation as important, fair, motivating, and useful (e.g., “The evaluation showed how much I learned.”)

Interviews (each 30-45 minutes) were conducted with one teacher in each subject at Woodville and pairs of teachers for each subject at Bayview. Teachers were asked to identify the topics covered in their course and the number of periods devoted to each topic, the text book (if one was used), the key learning outcomes addressed and the amount of time devoted to the specific learning outcomes that could be used by students in building their marble machines.

Treatment Conditions

Although teachers in both schools covered the same provincial curriculum in all three subjects, the programs in the schools differed in several ways:

1. Students in Bayview (but not Woodville) were blocked timetabled into mathematics, science and technology for three 85 minute periods each day for half the year. For most of the semester students were taught each subject separately by a single teacher. On seven occasions students applied what they had learned in a series of projects that required the assembly of knowledge and skill from all three subjects. When introducing new material, Bayview teachers emphasized that concepts and skills from one subject could be applied in another and reminded students that they would be required to do so in the culminating projects, although the projects were not described in advance and the specific physical and intellectual tools students would need were not identified. The links between subject knowledge and project tasks were made explicit in the debriefing following each project and individual student

feedback. In Woodville, teachers emphasized the importance of transfer of subject knowledge to real world problem solving and gave examples, but students were not required to demonstrate application.

2. Although content coverage was similar in both schools for the material tested by Marble Machine project, Bayview teachers made room for the MST activities by covering fewer topics, especially in science and mathematics. The topics deleted by Bayview teachers (e.g., linear inequalities) were perceived by teachers in both schools to be less important than the topics retained. Woodville teachers had also deleted topics when all schools were required by the province to destream (detrack) their grade 9 programs but the cuts in Woodville were not as deep.
3. Bayview teachers collaboratively arranged the topics in their subjects. The six teachers negotiated a sequence intended to fit the three subjects together as a coherent whole. A central criterion in the realignment was preparation for the forthcoming projects. In Woodville, each teacher determined topic sequence independently, considering only continuity within the subject, without regard for decisions made by teachers of other subjects. These curriculum decisions reflected cultural differences between the schools. The grade 9 mathematics, science, and technology teachers were timetabled so that they had a common preparation period. They met every second day as a group, sometimes more frequently, to coordinate their programs. The Woodville teachers of grade 9 mathematics, science, and technology never met as a group and rarely discussed their programs with one another.

4. Bayview teachers emphasized a common framework for solving problems. The district's 5-step inquiry process was introduced by all teachers at the beginning of the year and was frequently cited during problem solving tasks. Teachers demonstrated how the steps were implemented in their own subject and how that differed from implementation in other subjects. In Woodville the 5-step inquiry process was a main theme only in science and technology and neither teacher described how implementation would vary by subject.
5. Instructional practices in the two schools were very similar in science. Teachers in both schools were committed to some elements of "teaching for understanding" reforms, emphasizing hands-on activities, students constructing meaning in dialogue with their teacher and peers, the primacy of the experimental method as a way of knowing, and the application of science to societal issues. The Bayview technology and mathematics teachers also attempted to implement constructivist approaches in their classrooms, although to a lesser degree. In Woodville the mathematics teacher was very opposed to reform ideals and the technology teacher included elements of traditional and reform teaching. The Bayview teachers were committed to curriculum integration (the mathematics teachers to a lesser degree). In Woodville the science and technology teachers had been considering integration for some time and at the end of the study they began to incorporate some of Bayview's program into their own.

Procedures

The pre-test motivation survey was administered in both schools in early September 1995 and the results were used to form three person groups. Students were observed constructing their

towers (the pre-test task) near the end of September. From September to January teachers taught mathematics, science, and technology separately (Woodville) or in an integrated program (Bayview). Teachers (three in Woodville and six in Bayview) were interviewed about their programs in mid-December. In the second week of January 1996 students in both schools were observed while building their Marble Machine projects (the post-test task). They were interviewed about the learning outcomes they applied, and completed the motivation and evaluation attitude surveys. During February and March the knowledge application interviews and recordings of groups were transcribed; interviews and diagrams were coded.

All variables were normalized using log transformations. Multivariate analyses of variance were conducted in which the dependent variables were students' post-test (i) ability to apply discipline-specific and shared MST outcomes (4 variables), (ii) group productivity (8 indicators of diagram quality), (iii) ability to work together (6 variables), and (iv) attitudes to evaluation (2 variables). The independent variables were school and gender. Although pretest data were available for the working together variables, pretest scores did not predict post-test performance and for that reason were not included as covariates. For the goals orientation analyses, a multivariate analysis of covariance was conducted in which the dependent variables were post-test orientations to learning, the covariates were students' pretest orientation scores, and the independent variable was school. In addition, effect sizes were calculated (Glass, McGaw, & Smith, 1981) when significant school differences were found.

Results

Table 3 displays the unadjusted means and standard deviations for the variables in the study. In the table the data for student ability, goal orientations, and evaluation attitudes are at the individual student level. The post-test knowledge application data is also at the individual student level but the n is smaller because a sample of students was drawn for the interviews. The interaction and productivity data are group scores.

Table 3 About Here

The internal consistencies of the composite scales (Cronbach's alpha) were acceptable for mastery orientations (7 items) .75 (based on the pre-test scores) and for the diagram scale (8 items) .76. The internal consistencies for the other scales, each based on only three items were weaker: ego orientations was .55 and affiliative goals orientation was .59

Pre-test Equivalence of Groups There were some differences between schools on entry to the program. In terms of goal orientations, Bayview students were less likely to be motivated by a desire to spend time with their friends [$t(132)=-3.33, p \leq .001$]. This difference is an important one because pre-test scores on the affiliation variable predicted post-test affiliative goals [$r=.342, p \leq .001$]. In terms of interaction patterns, Bayview students were more likely on the pre-test to handle lab materials constructively together [$t(31.37)=4.38, p \leq .001$] but this pre-test variable did not predict interaction patterns on the post-test.

Student Achievement

The first indicator of student achievement was the quality of the diagrams produced by students, determined by a multivariate analysis of variance in which the dependent variables were

the post diagram scores listed in Table 1. The independent variables were gender and treatment condition. The multivariate gender X treatment interaction was not statistically significant [$F(8,47)=1.36, p=.225$], nor were there any univariate effects. For gender there was no multivariate [$F(8,47)=1.02, p=.369$] or univariate main effects. There was a multivariate main effect for school. The integrated curriculum groups developed significantly better diagrams [$F(8,47)=65.84, p\leq.001; ES=1.14$]. The univariate effects indicated that Bayview students were more likely to clearly mark all dimensions [$F(1,103)=4.45, p=.037$], display hidden views in their diagrams [$F(1,103)=49.81, p\leq.001$], use a 1:1 scale as required in the directions for the task and [$F(1,103)=105.38, p\leq.001$], and produce diagrams that were congruent with their thumbnail sketches [$F(1,103)=297.35, p\leq.001$]. In contrast Woodville students were more likely to use metric scale in all dimensions [$F(1,103)=10.13, p<.002$].

The second indicator of achievement was knowledge application. Table 4 summarizes the results of a multivariate analysis of variance in which knowledge application scores were the dependent variables and treatment condition and gender were independent variables. Table 4 shows there were gender X school interactions. The adjusted means (shown in Table 5) indicate that females scored higher in the integrated school than in the control on application of knowledge unique to science and on learning outcomes that were shared by all three subjects. The only significant main effect found that integrated students scored higher than control students on their ability to apply learning outcomes shared by the three subjects [$ES=.92$]. There were no differences between schools on the outcomes unique to each subject. In other words, curriculum

integration increased students' ability to apply learning outcomes that were important in all three subjects without reducing achievement in the learning outcomes unique to each subject.

Tables 4 and 5 About Here

We re-examined the knowledge application data in terms of the goal orientations of students. We ran a series of analyses of covariance in which the dependent variable was post-test knowledge application score in one subject (mathematics, science, technology or shared MST outcomes) and the independent variables were treatment condition and one of the goal orientation variables (mastery, ego or affiliative orientation). The only statistically significant finding was for the mathematics application scores when pretest mastery orientation was introduced as a covariate. The overall model was significant [$F(3,31)=3.44$, $p=.030$]. There was a main effect for school [$F(1,31)=5.33$, $p=.029$] and for mastery orientation [$F(1,31)=5.29$, $p<=.029$]. The school X orientation interaction was also significant [$F(1,31)=5.38$, $p=.028$]. Inspection of the means indicated that the curriculum integration produced higher mathematics application scores when students' pretest orientation was controlled. Since simultaneous tests inflate the risk of Type I error, a modified Bonferroni procedure was used. The p value for the strongest contrast was determined by dividing the alpha by the number of contrasts (i.e., $p=.05/4=.013$). The p value for the next strongest contrast was determined by dividing the alpha by the number of remaining contrasts (i.e., $p=.05/3=.017$) and so on (Serlin, 1993). When the Bonferroni procedure was applied, the finding that curriculum integration produced higher mathematics application scores no longer reached statistical significance.

Student Motivation The effects of curriculum integration on student motivation were examined in an analysis of covariance in which the dependent variables were students' post-test orientations (mastery2, ego2, and affiliative2), the covariates were pre-test orientation scores (mastery1, ego1, and affiliative1), and the independent variable was school. Table 6 summarizes the results. There were no treatment X covariate interactions (only the multivariate results are shown in the table). There was a main effect for each of the covariates. In every case the pre-test score for a given orientation predicted the post-test score for the same orientation and none other. There was also a main effect for school. Students in the integrated school were more likely on the post-test to score high on mastery orientation than students in the other school, meaning that Bayview students were more likely to approach school tasks with the goal of learning a new skill or concept.

Table 6 About Here

Ability to Work Together The post-test task generated lower levels of interaction than the pre-test task, in part because the directions called for students to produce individual thumbnail sketches before selecting a single group diagram. Consequently the means for being on-task alone were higher and the means for working together were lower on the post-test. In addition the pre-test interactions did not predict post-test interactions. A multivariate analysis of variance was conducted in which six interaction behaviours were the dependent variables and the independent variables were school and gender. The multivariate school X gender interaction was not statistically significant [$F(6,41)=.56$, $p=.760$], nor were any of the univariate effects. For gender there were no multivariate [$F(6,41)=.22$, $p=.969$] or univariate main effect. There was a

significant multivariate effect for school [$F(6,41)=23.52$, $p<.001$]. Bayview students were more likely than Woodville students to be talking about the project together [$F(1,90)=42.80$, $p.001$; $ES=2.28$] and to be watching other group members build the machine or listening to on-task project talk [$F(1,90)=29.81$, $p<.001$; $ES=1.34$]. Bayview students were also less likely to be off-task [$F(1,90)=46.56$, $p<.001$; $ES=-1.26$] than Woodville students.

Evaluation Attitudes A multivariate analysis of variance was conducted in which the dependent variables were attitudes to evaluation (to exams and to project-based evaluation) and the independent variables were gender and school. The results are summarized in Table 7. There were no gender X school interactions or main effects for gender. Integrated students were not as positive as controls about evaluation when it took the traditional form of a mid-term exam [$ES=-.55$]. Bayview students were more positive than their Woodville peers when student evaluation was based on their project work [$ES=.68$].

Table 7 About Here

Discussion

The findings suggest that the adoption of curriculum integration had a beneficial impact on students. In terms of (i) student achievement, curriculum integration contributed to stronger diagramming skills and to a better application of learning outcomes that were shared by the three disciplines. In addition, female students performed better on science outcomes in an integrated setting than they did when each subject discipline was taught separately. In one sense this is unalloyed good news: the benefits of curriculum integration (better achievement of common outcomes) were realized at no cost (i.e., no loss of achievement in outcomes unique to each

discipline with some gains in some instances). Readers should keep in mind that the outcomes that were measured were limited to a small set required by the Marble Machine project. It would be risky to conclude that all important discipline-specific outcomes covered in the three courses would show similar results.

Curriculum integration contributed to (ii) student motivation. Bayview students were more likely to maintain a mastery orientation to learning than students in the segregated course setting. Students who approach school tasks with a mastery orientation (i.e., with the goal of learning something) consistently adopt more powerful learning strategies and learn more than students who approach school tasks with other motivations, such as impressing their teacher and engaging in social interaction with their friends (Urduan & Maehr, 1995).

Curriculum integration contributed to (iii) students' ability to work together. The findings indicate that Bayview students were engaged in more productive task talk and less off-task talk, than students in the segregated setting.

Curriculum integration had a mixed effect on (iv) student attitudes toward evaluation. Bayview students were more positive toward evaluation involving group projects than students in the comparison school but the opposite was the case for attitudes toward mid-term exams. In the absence of data on evaluation attitudes prior on entry to the program, it is difficult to estimate the effects of curriculum integration.

Implications for Teachers

Secondary school teachers are receiving mixed messages about curriculum integration from curriculum reformers. On the one hand teachers are told that the department is the source of serious

problems. Strong departmental identities create cleavages among teachers, imprison student learning within disciplinary cells, limit curricular options and the transfer of teaching ideas, and constrain the development of a school vision (Hargreaves, 1994; McLaughlin & Talbert, 1990; Siskin, 1994). Curriculum integration is from this perspective a strategy for breaking free of departmental constraints to the improvement of teaching and learning. But teachers are also being told that the key to instructional improvement is “teaching for understanding”. Excellence in teaching requires a profound grasp of disciplinary content and of methods for presenting such content to students. From this point of view curriculum integration is likely to lead to a deterioration in instruction, with negative effects on student performance. Evidence is accumulating that even experienced teachers behave differently when they are teaching outside the content area familiar to them (Carlsen, 1993; Hashweh, 1987; Ringstaff & Haymore, 1987; Sanders, Borko, & Lockard, 1993).

Very few empirical studies have examined the teacher and student effects of curriculum integration and previous evaluations of attempts to integrate science, mathematics, and technology produced mixed results. The study reported here presents a more optimistic picture, one in which student achievement of shared curricular goals was attained at no cost to discipline-specific outcomes. We attribute these positive results to the project-based approach to curricular integration that was implemented. In Bayview science, mathematics, and technology continued to be taught by specialists. Although teachers met frequently, becoming more aware of expectations in other subjects, they were not required to teach these other subjects nor were they required to sacrifice disciplinary integrity.

Our experience in this study leads us to two recommendations for schools that are considering curriculum integration. The first is that the kind of integration chosen is more important than whether or not to integrate. We recommend that teachers adopt a project-based approach because it enables the benefits of integration (in terms of transfer, focus, and motivation) to be attained without the costs of

teaching outside one's area or reducing standards in the discipline. Our second recommendation has to do with the need for teachers to take time to learn how to integrate before leaping into an overly ambitious program. The integrated math, science and technology program that was examined in this study developed over a four-year period. In the first year one teacher from each of the three subjects created a single integrated project that was implemented in a single advanced placement class. As teachers became more experienced they augmented the number of projects and increased the number of students and teachers involved. They went through an extended, cyclical process of development, evaluation, and revision. Teachers who leap into ambitious integration programs developed by others without first engaging in the lengthy professional learning process that the Bayview teachers went through are unlikely to get the same results.

Endnote

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² Teachers were asked, in same-subject pairs in Bayview and individually in Woodville, “what intellectual or physical tools unique to your subject could be used by students in completing the task?” and “what other tools, not unique to your subject, could students use?” There was a high degree of agreement in their responses. The final list included all the suggestions made by the teachers.

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Table 1 Coding Scheme for Sketches and Diagrams (all items scored 0-2)

D1	.all dimensions clearly marked
D2	.all dimensions in metric scale
D3	.3 views shown (front, side, top)
D4	.hidden views displayed
D5	.1:1 scale
D6	.all lines made with a straight edge rather than by hand
D7	.feasible (this was a high inference item in which the coder judged whether the machine would stand up if it was constructed as shown in the diagram; the most common failings were poor supports [given 1] or insufficient detail to tell [given 0])
D8	.final diagram congruent with one of thumbnail sketches

Table 2: Coding Scheme for Knowledge Application Interviews

Dimension	Scale Values
Identification of	0 - discussed only after prompted
Learning Outcome	1 - identified without prompting; proper label not given
	2 - identified without prompting; proper label given
Understanding of	0 - no understanding or misconception
Learning Outcomes	1 - partial understanding
	2 - accurate understanding
Use of Learning Outcomes	0 - not used or incorrectly used
	1 - recognized relevance of concept but did not use it
	2 - appropriate use

Table 3: Unadjusted Means and Standard Deviations

	Bayview			Woodville		
	N	X	SD	N	X	SD
Pre Goals Orientation (motivation)						
- mastery	78	2.87	0.55	51	2.92	0.50
- ego	81	2.39	0.65	53	2.16	0.65
- affiliative goals	81	2.26	0.68	53	2.65	0.66
Post Goals Orientation (motivation)						
- mastery	70	2.80	0.55	45	2.48	0.76
- ego	74	2.26	0.74	46	1.93	0.65
- affiliative goals	75	2.79	0.68	45	2.44	0.72
Pre Interactions						
- On-task alone	21	0.70	0.93	20	2.30	2.54
- Handling equipment constructively together	21	14.19	2.51	20	9.53	4.07
- Handling equipment together in conflict	21	0.08	0.23	20	0.02	0.08
- Talking together about the project	21	1.36	0.81	20	2.13	1.17
- On-task watching or listening	21	2.67	1.46	20	3.45	3.19
- Off-task	21	1.03	0.86	20	2.63	3.32
Post Interactions						
- On-task alone	19	6.20	2.50	17	6.99	3.94
- Handling equipment constructively together	19	2.79	2.33	17	3.29	2.93
- Handling equipment together in conflict	19	0.05	0.17	17	0.06	0.18
- Talking together about the project	19	5.17	1.47	17	2.07	1.36
- On-task watching or listening	19	4.53	2.19	17	1.99	1.89
- Off-task	19	1.11	1.27	17	5.62	3.58
Group Productivity						
- Pre (Height, in cm.)	29	54.83	17.69	18	42.47	25.71
- Post (Distance, in cm.)	19	72.42	99.51	17	150.88	137.98
- Post (Diagrams)	19	8.79	3.84	20	5.35	3.00
Post Knowledge Application						
- Technology	18	4.41	1.20	21	3.56	1.62
- Science	18	2.37	1.33	21	2.59	1.43
- Mathematics	18	2.58	1.35	21	2.56	1.01
- shared MST	18	4.07	0.74	21	3.52	0.60
Post Evaluation Attitudes						
- Mid-term exam	65	3.94	0.48	46	4.20	0.47
- Appraisal of group work	72	3.73	0.52	46	3.26	0.69
	N	%		N	%	

Integrating Math, science, technology 33

Gender				
Male	35	40.7	31	57.4
Female	51	59.3	22	40.7
Native	0	0	13	9.3

Table 4: Summary of Multivariate Analysis of Variance for Knowledge Application Variables by Subject

	Gender x School	Gender	School
Total Multivariate	F(4,31)=1.58	F(4,31)= .65	F(4,31)=2.65
Technical	F(1,34)=1.85	F(1,34)= .34	F(1,34)=3.93
Science	F(1,34)=4.42*	F(1,34)= .79	F(1,34)= .01
Math	F(1,34)= .51	F(1,34)=1.17	F(1,34)= .06
Shared MST	F(1,34)=4.13**	F(1,34)= .13	F(1,34)=7.77***

* $p=.043$ ** $p=.050$ *** $p=.009$

Table 5 Adjusted Means and Standard Deviations for Gender by School Interaction (n=39)

	Bayview		Woodville	
	Mean	SD	Mean	SD
Males				
Science outcomes	.46	.17	.59	.14
Shared MST outcomes	.68	.06	.66	.06
Females				
Science outcomes	.53	.19	.43	.25
Shared MST outcomes	.72	.06	.64	.06

Table 6: Summary of Multivariate Analysis of Variance for Evaluation Attitudes

	Gender x School	Gender	School
Total Multivariate	F(2,103)=1.53	F(2,103)=1.35	F(2,103)=24.70*
Exam Evaluation	F(1,104)=2.86	F(1,104)= .63	F(1,104)= 8.26**
Project Evaluation	F(1,104)=1.62	F(1,104)= .72	F(1,104)=16.84***

*p=.000 ** p=.005 *** p=.000